

DEVELOPMENT OF CARBON FOOTPRINT QUANTIFICATION AND  
REDUCTION (CAFQUAR) ASSESSMENT TOOL FOR SELECTED  
NON-RESIDENTIAL BUILDINGS

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## DEDICATION

This work is dedicated to my parents, wife, children, brothers and sisters



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## ABSTRACT

Greenhouse Gas (GHG) emission is the major consequences of industrial revolution, technology advancement and urbanisation. Building is one of the major factor of these and hence one of the major contributor to global GHG emissions. To ensure sustainable recognition in the building sector, several assessment tools were developed. Some of these tools assessed the sustainability of built environment and others quantify either water, energy, transport or greenery associated emissions hence partially capture building life cycle phase categories. The study aimed at developing an assessment tool for assessing building design emission reduction and operational emission quantification and reduction covering energy, water, transportation, waste and greenery as categories. These categories, parameters and points allocation were obtained from reviewing literatures (eleven rating systems and international standards and reports) and were divided into 27 parameters and 70 sub-parameters. The buildings are graded with star rating and together with the points allocation are distributed to a maximum of 100 Points. The performance of the tool was evaluated by considering the tool feasibility, measurability, applicability, relevancy and its compliance with international standards. These criteria were explained in the pilot and case studies assessment, comparison with other tools and consultation with stakeholders. The pilot and case study assessment cover library, four academics, and office buildings. Some of the case studies have an excellent performance grade which can be seen from their net Carbon Footprint (CFP) and carbon indexes results. This defines the tool ability to compute the net building operational GHG emission and emission density over the total floor area. These processes and criteria fulfilment describe the tools potentials in covering wider scope in relation to GHG emission in term of categories, parameters and its application to variety of non-residential buildings. It is the first tool that consider quantification of all the emission sources categories of the operational phase. The tool is useful to industries for emission quantification and reduction and to government for monitoring their industrial compliance to policies and standards.

## ABSTRAK

Pelepasan Gas Rumah Hijau (GHG) adalah disebabkan dari revolusi industri, kemajuan teknologi dan urbanisasi. Bangunan merupakan salah satu faktor utama dan ianya juga salah satu penyumbang utama kepada pelepasan GHG secara global. Untuk memastikan pengiktirafan berterusan dalam sektor bangunan, beberapa alat penilaian telah dibangunkan. Sesetengah alat ini menilai kemampuan persekitaran yang dibina dan juga mengukur air, tenaga, pengangkutan atau penghijauan yang berkaitan dengan pelepasan gas ini dan sebahagiannya merangkap kategori fasa kitaran hayat bangunan. Kajian ini bertujuan untuk membangunkan alat penilaian untuk menilai pengurangan pelepasan dari rekabentuk bangunan serta pelepasan dan pengurangan dari operasi yang meliputi kategori tenaga, air, pengangkutan, sisa dan kehijauan. Dari kategori ini, parameter dan peruntukan mata diperoleh daripada kajian literatur (sebelas sistem penarafan dan piawaian antarabangsa dan laporan) dan dibahagikan kepada 27 parameter dan 70 sub-parameter. Bangunan ini dinilai dengan rating bintang dan juga dengan peruntukan nilai mata yang mana mempunyai nilai maksimum iaitu 100 mata. Prestasi alat penilaian ini dinilai dengan mempertimbangkan kebolehlaksanaan alat, ukuran, kebolehgunaan, relevansinya dan pematuhannya dengan piawaian antarabangsa. Kriteria ini dijelaskan dalam penilaian kajian kes, perbandingan dengan alat penilaian yang lain dan perundingan yang dilaksanakan dengan pihak berkepentingan. Penilaian kajian kes ini meliputi bangunan perpustakaan, empat bangunan akademik dan bangunan pejabat. Sebahagian kajian kes mempunyai gred cemerlang yang boleh dilihat dari nilai *Carbon Footprint* (CFP) dan hasil indeks karbon. Ini menunjukkan keupayaan alat ini untuk menilai pelepasan GHG bersih dari bangunan dan ketumpatan pelepasan melawan keluasan lantai. Proses dan kriteria ini menggambarkan potensi alat penilaian ini dalam meliputi ruang lingkup yang lebih luas berkaitan dengan pelepasan GHG dari segi kategori, parameter dan penggunaanya dalam pelbagai jenis bangunan bukan kediaman. Ini adalah alat pertama yang menganggap kuantifikasi semua sumber pelepasan sumber fasa operasi. Alat ini berguna untuk industri bagi mendapatkan kuantiti dan pengurangan pelepasan dari bangunan dan ianya dapat membantu kerajaan untuk memantau pematuhan pihak industri terhadap dasar dan piawaian yang telah ditetapkan.

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## LIST OF SYMBOLS AND ABBREVIATIONS

CF	- Control Factor
D,d	- Distance in (m)
ETR <sub>0</sub>	- Reference Evapotranspiration Rate
F <sub>cl</sub>	- Ratio of Body Surface Area (fully cloth and when nude)
H <sub>c</sub>	- Convection Heat Transfer Coefficient
I <sub>cl</sub>	- Thermal Resistance of Clothing
IE	- Irrigation Efficiency
K	- Thermal Conductivity of a Material
K <sub>MC</sub>	- Microclimate Factor
kPa	- Kilo Pascal
K <sub>s</sub>	- Species Factor
M	- Metabolism
OF	- Solar Orientation Factor
Pa	- Partial Water Vapour Pressure
Q	- Heat Transfer by a Material
R	- Thermal Resistance
SC	- Shading Device of Fenestration System
T	- Temperature
T <sub>a</sub>	- Average Air Temperature
T <sub>cl</sub>	- Surface Temperature of Clothing
T <sub>mrt</sub>	- Mean Radian Temperature
U <sub>f</sub>	- Thermal Transmittance of Fenestration System
U <sub>w</sub>	- Thermal Transmittance of Opaque Wall
V <sub>a</sub>	- Average Velocity of Air
W	- External Work
α	- Solar Absorptivity of the Opaque Wall
#	- Percentage Increase

*	- Space to be filled by the assessor
**	- Redistribution of all the parameters and points allocation
***	- Parameters and sub-parameters affected after review
ACEM	- Association of Consulting Engineers Malaysia
AR	- Assessment report
AR5	- Fifth Assessment Report
AWT	- Average Waiting Time
BCI	- Overall Building Carbon Index
BEAM	- Building Environment Assessment Method
BECI	- Building Energy Carbon Index
Breem	- Building Research Establishment Environment Assessment Method
BTCI	- Building Transportation Carbon Index
BWACI	- Building Waste Carbon Index
BWCI	- Building Water Carbon Index
CAFQUAR	- Carbon Footprint Quantification and Reduction Assessment Tool
CFET	- Carbon Footprint Estimation Tools
CFP	- Carbon Footprint
CO <sub>2e</sub>	- Carbon Dioxide Equivalent
DA	- Day Light Access
EDF	- Equivalent Doorstep Frequency
EF	- Emission Factor
FAR	- First Assessment report
FAR	- Fourth Assessment Report
FKAAS	- Faculty of Civil and Environmental Engineering
FPTP	- Faculty of Technology and Business Management
FPTV	- Faculty of Vocational and Technology Education
FSKTM	- Faculty of Computer Science and Information Technology
GBI	- Green Building Index
GESI	- Greenery Emission Sequestration Index
GHG	- Greenhouse Gas
GreenRE	- Green Real Estate
GWP	- Global Warming Potential
IPCC	- Intergovernmental Panel on Climate Change
JKR	- Ministry of Public Works



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